



Low Earth Orbiter



LAGEOS 1/2

Realization of reference frames based on integrated SLR measurements to LEO and LAGEOS satellites

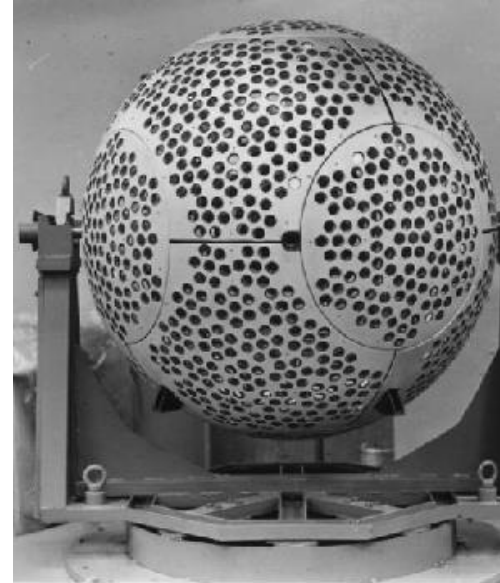
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Motivation



LAGEOS1/2



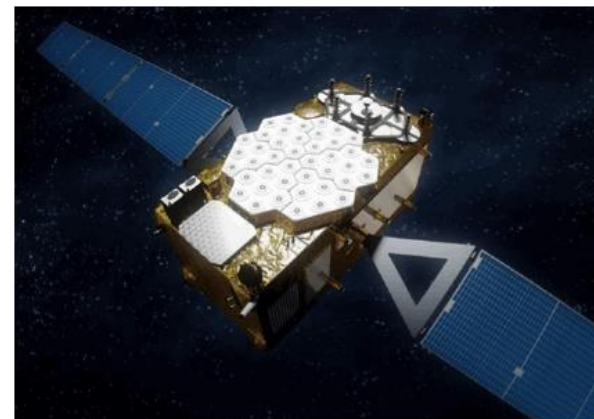
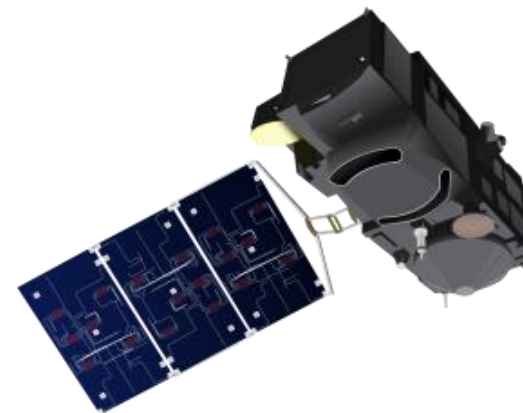
Etalon 1/2

Satellite Laser Ranging (SLR) measurements to passive geodetic satellites (LAGEOS & Etalon) are used for the realization of reference frames (e.g. ITRF2014)

Motivation



retroreflectors



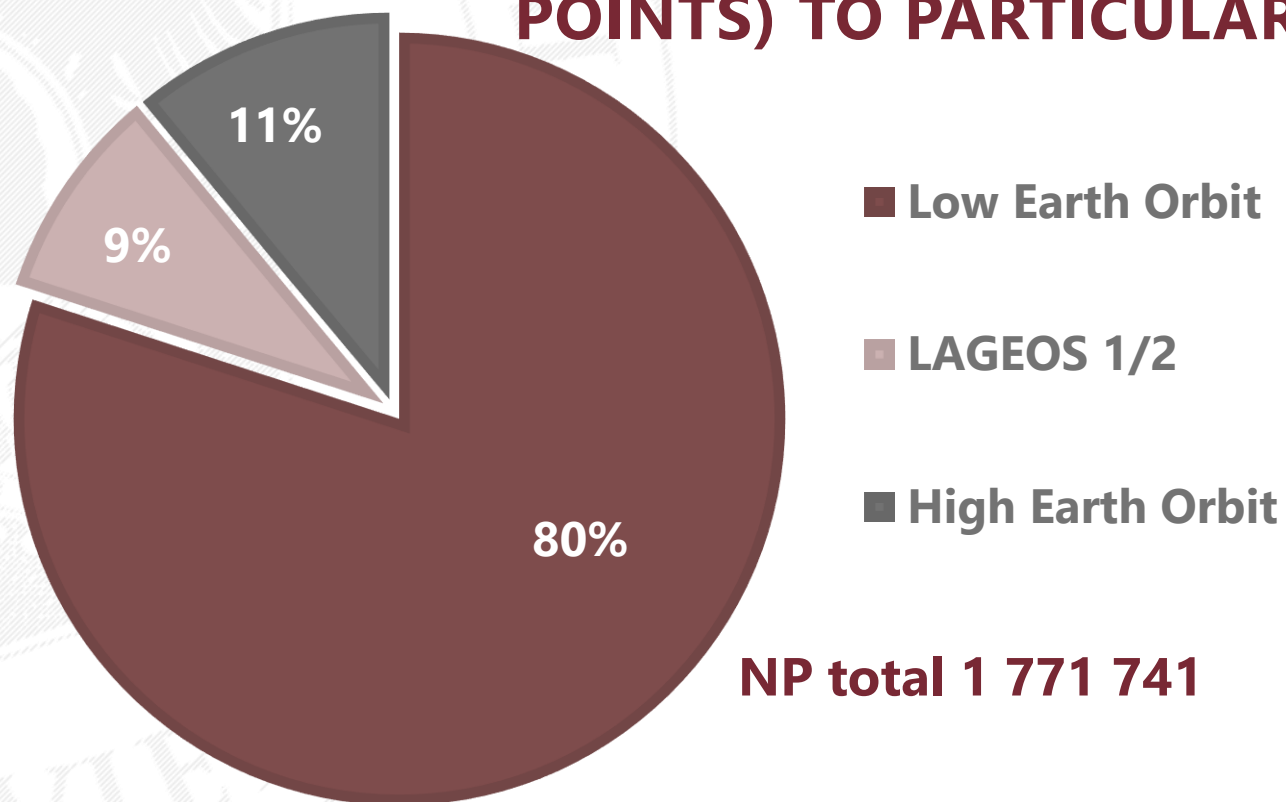
GNSS or active Low Earth orbit (LEO) satellites are equipped with retroreflectors, which allow for SLR measurements

Motivation



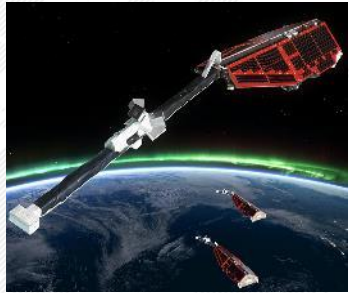
International Laser Ranging Service (ILRS) initiates a series of intense tracking campaigns for GNSS and LEO satellites

PERCENTAGE OF SLR OBSERVATIONS (NORMAL POINTS) TO PARTICULAR SATELLITE TYPES IN 2017

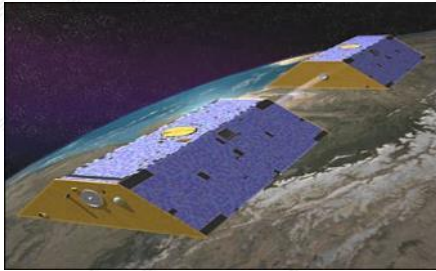


Only 9% of all SLR measurements are used currently for the reference frames realization, determination of Earth rotation parameters (ERP), and geocenter coordinates

SLR measurements



SWARM-A/B/C



GRACE-A/B



Jason-2



TerraSAR-X



SENTINEL-3A

- *ESA, NASA, EUMETSAT, GFZ DLR, CNES*
- *active Low Earth Orbit satellites*
- *GNSS receivers onboard*
- *satellites with different weight, shape, equipment, orbit parameters*
- *precise GPS-based orbits and attitude data*

Active satellites

SLR



orbit validation

LAGEOS-1, LAGEOS-2

- *NASA and ASI*
- *used for relativistic effects, gravity field, geodynamics, ERP, geocenter coordinates research by SLR measurements*
- *passive, spherical, geodetic satellites, with low area-to-mass ratio*
- *equipped with 426 retroreflectors dedicated for SLR technique*

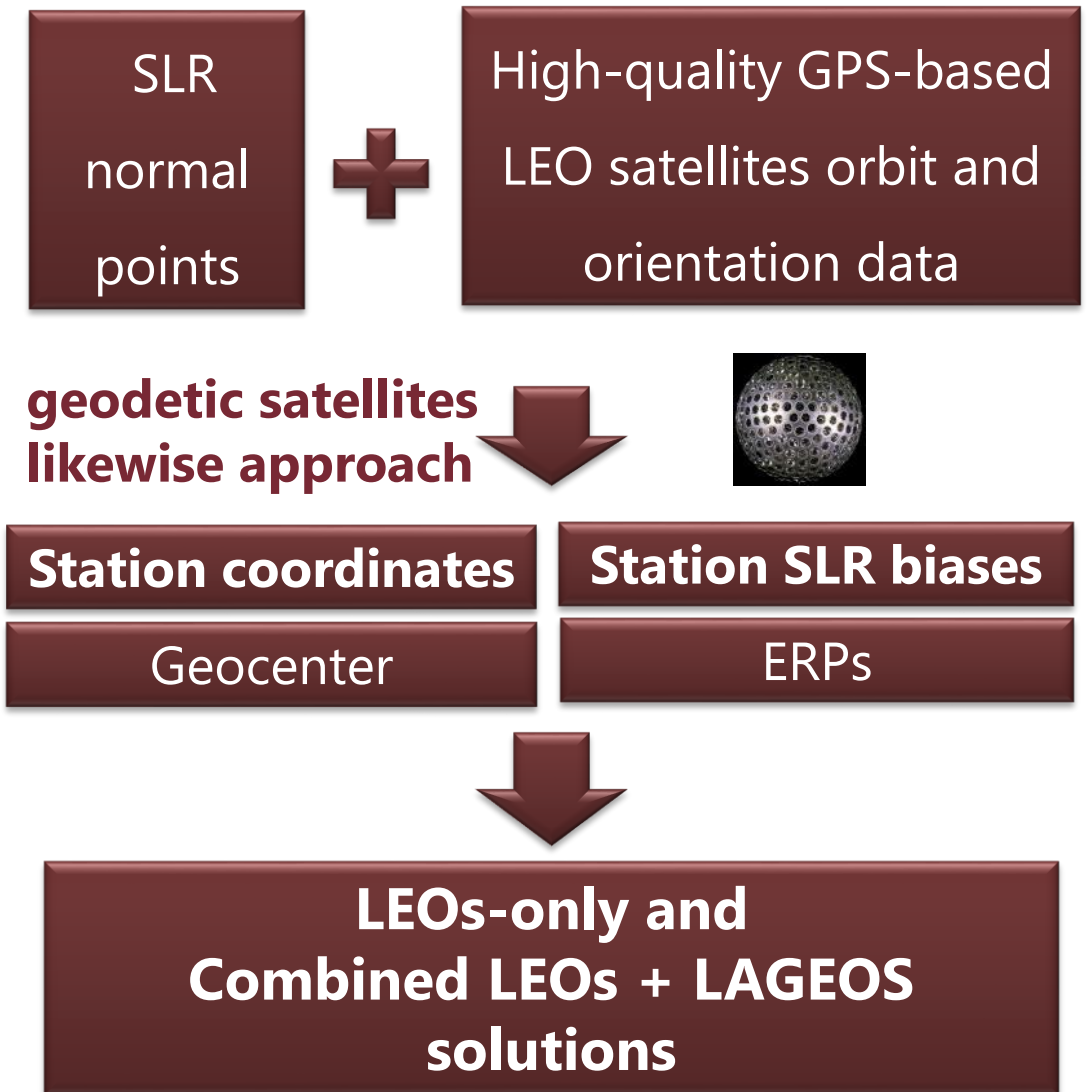
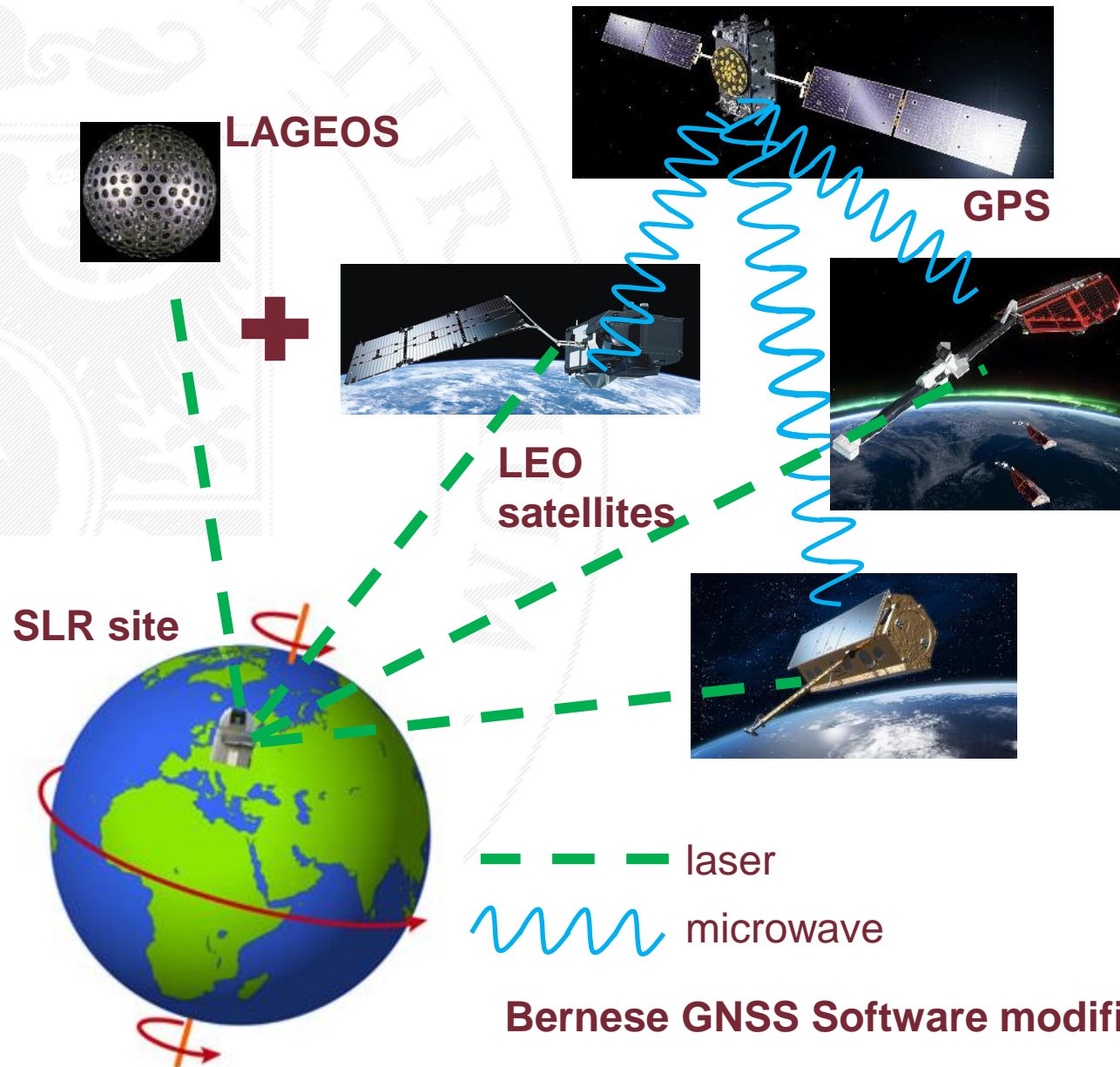
Passive satellites

SLR



station coordinates, geocenter coordinates, ERP, scale, relativistic effects validation

LEOs GNSS- and SLR- based analysis



Solution tests– SLR to LEOs

Solution tests: different network and parameters constraining and a different number of accumulated 1-day orbit combination

Test1: network constraining: no-net-translation (NNT) no-net-rotation (NNR) with estimation of parameters



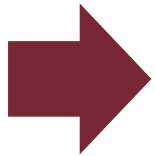
SLR station coordinates, geocenter, ERPs

Test2: network constraining: no-net-translation (NNT) no-net-rotation (NNR) without estimation of parameters



SLR station coordinates

Test3: no network constraining and without estimation of parameters



SLR station coordinates

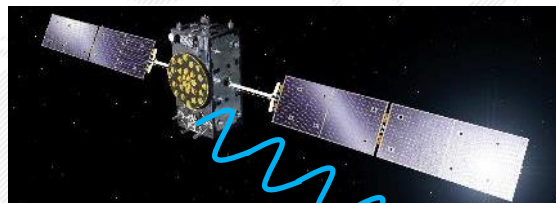
Time span: 2016-2017

LEO satellites
(fixed GPS-based orbits)



The issue of the reference frame differences

Test 1 with NNT/NNR constraints



GNSS – IGS14
integrated around
Center-of-Figure (CoF)

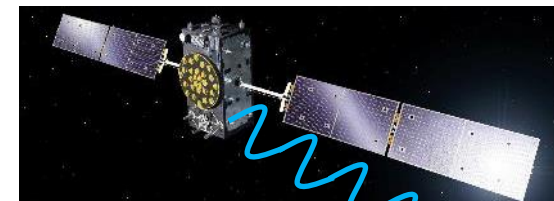


LEO – IGS14, but pseudo-stochastic orbit parameters are estimated → larger flexibility, close representation of the Earth's Center-of-Mass (CoM)



CoM vector w.r.t. CoF represents geocenter motion, but to what extent IGS14 and SLRF2014 are consistent

Test 3 no network constraints



GNSS – IGS14
integrated around
Center-of-Figure (CoF)

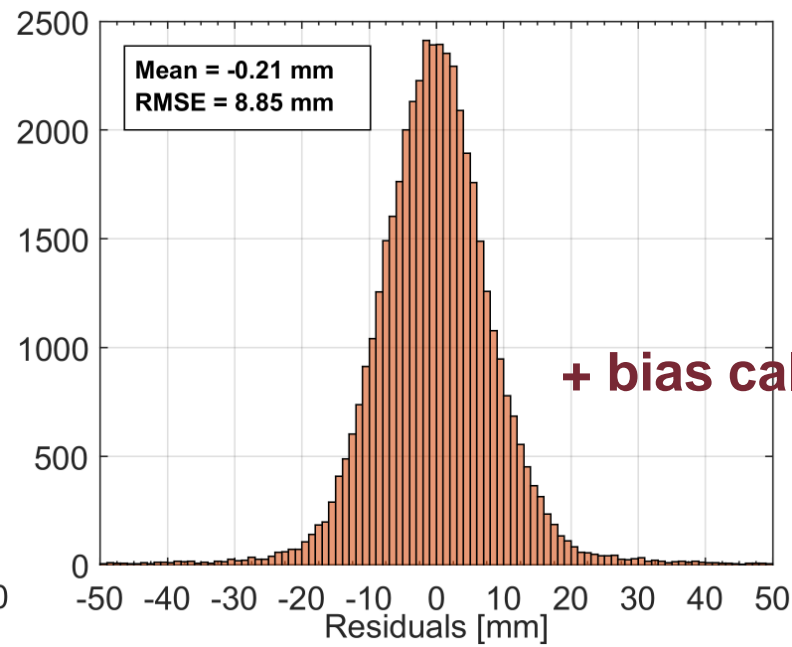
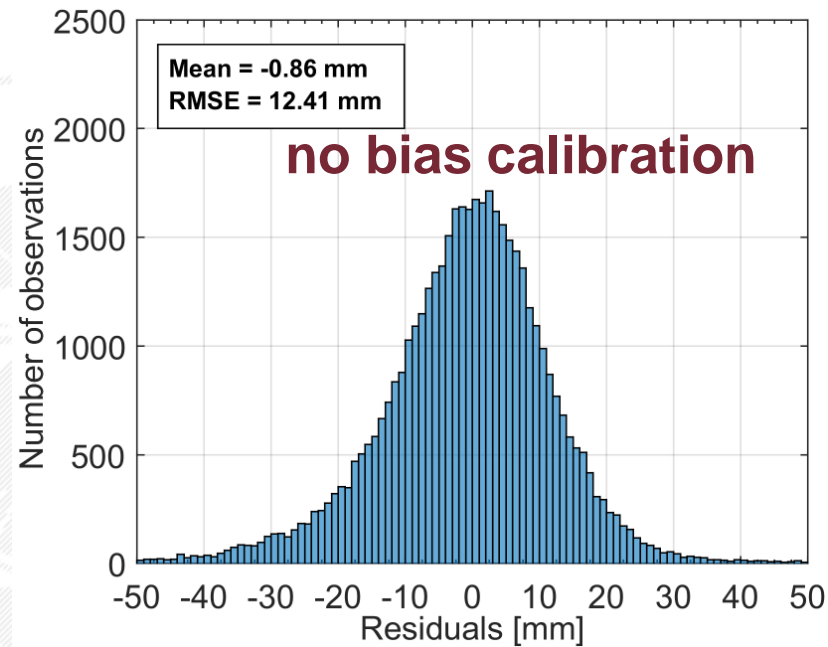
SLR sites IGS14
(reference frame
transferred through
LEO orbits)



LEO – IGS14,
reduced

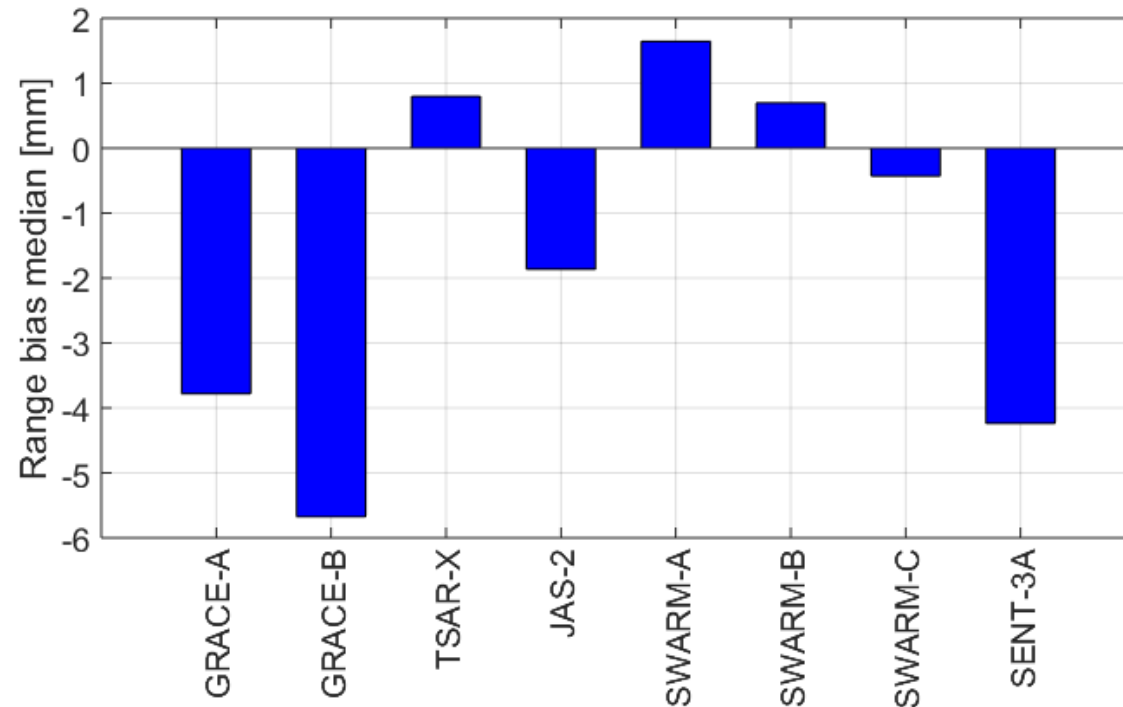


In SLR-PPP (test3)
SLR station coord.
are in IGS14



Importance of proper SLR station bias calibration for LEOs

Example of SLR residuals to Sentinel-3A GPS based orbits without and with bias calibration



Each satellite requires different bias correction

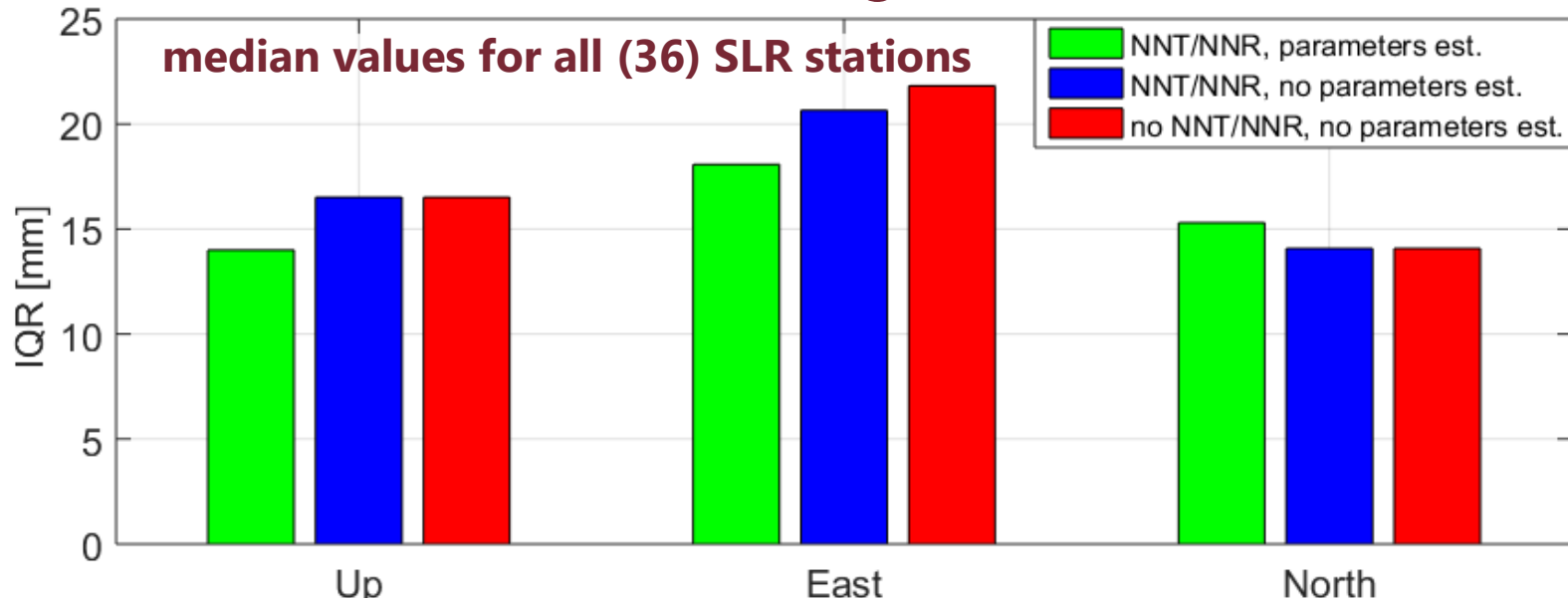


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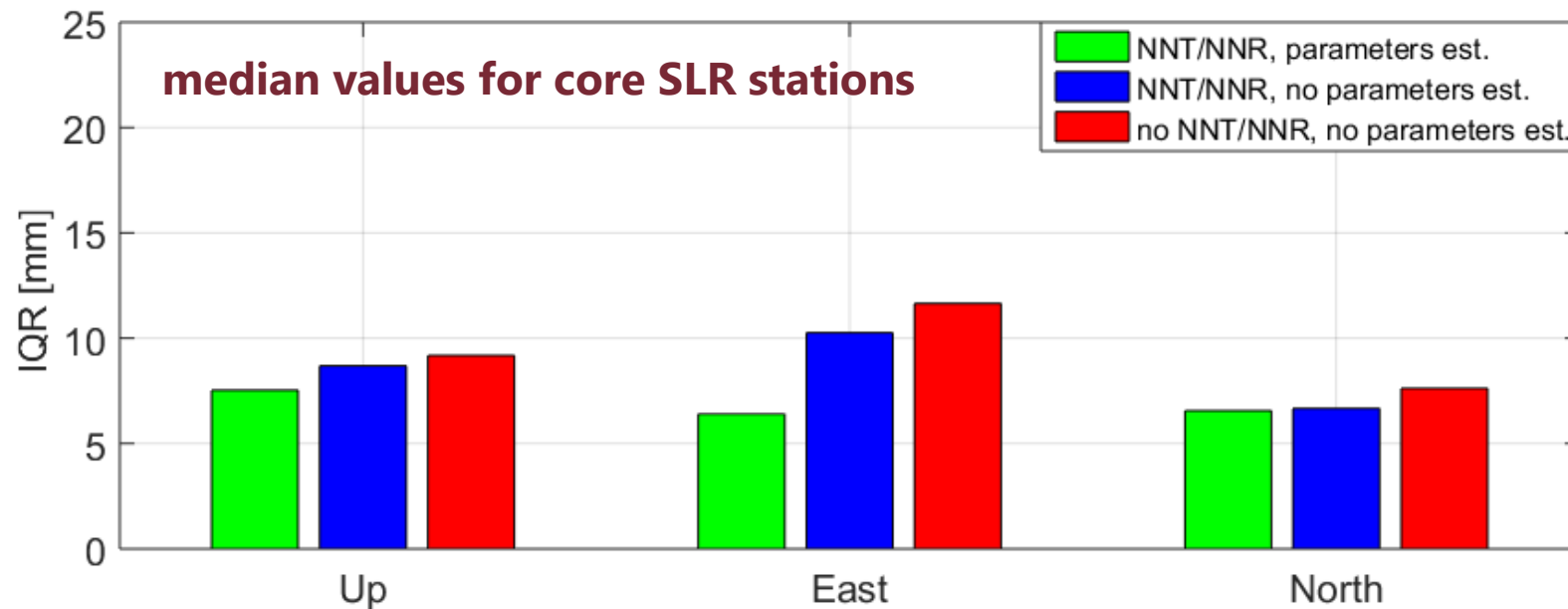
RESULTS

TEST 1: A different constraining for LEOs

Station coordinates
(w.r.t ITRF2014)



The positioning of **all SLR stations** with the accuracy at the level of **less than 22 mm**, even without network constraining

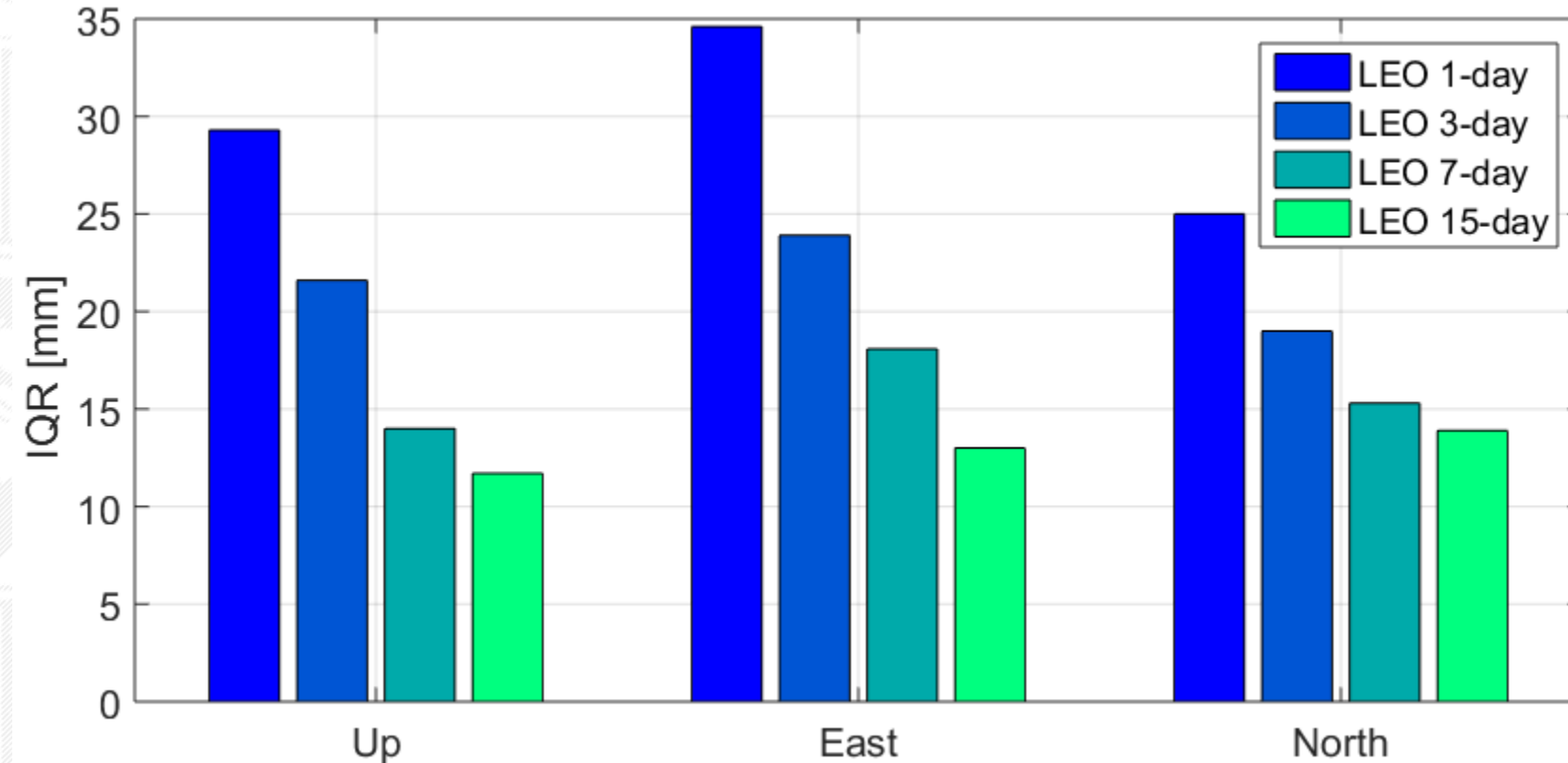


The positioning of **core SLR stations** with the accuracy at the level of **10 mm is possible!**

Even without network constraining (blue) provides proper station coordinates (8-12mm-top sites)

Core stations: Yarragadee, Greenbelt, Matera, Hartebeesthoek, Haleakala, Zimmerwald, Mt Stromlo, Graz, Herstmonceux, Potsdam

TEST 2: A different number of accumulated 1-day orbits- LEO



**Different number of accumulated orbits
median values for all (36) stations**

Statistics for all SLR sites

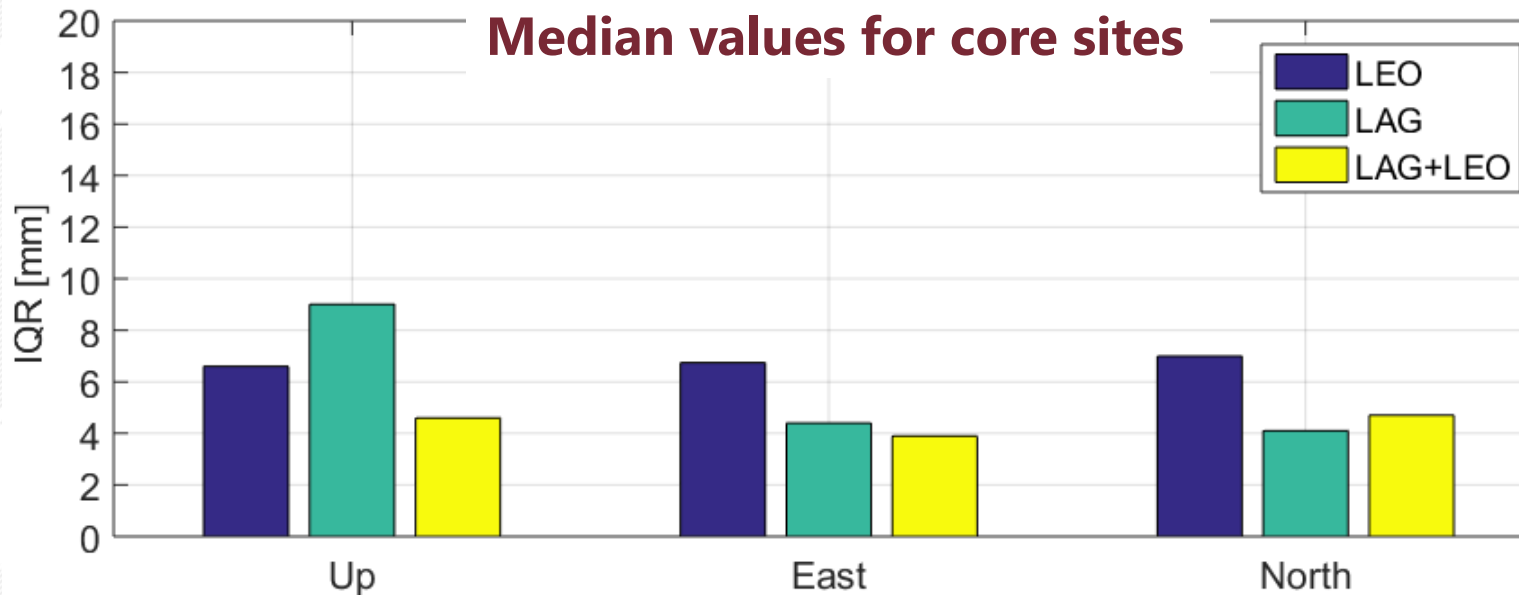
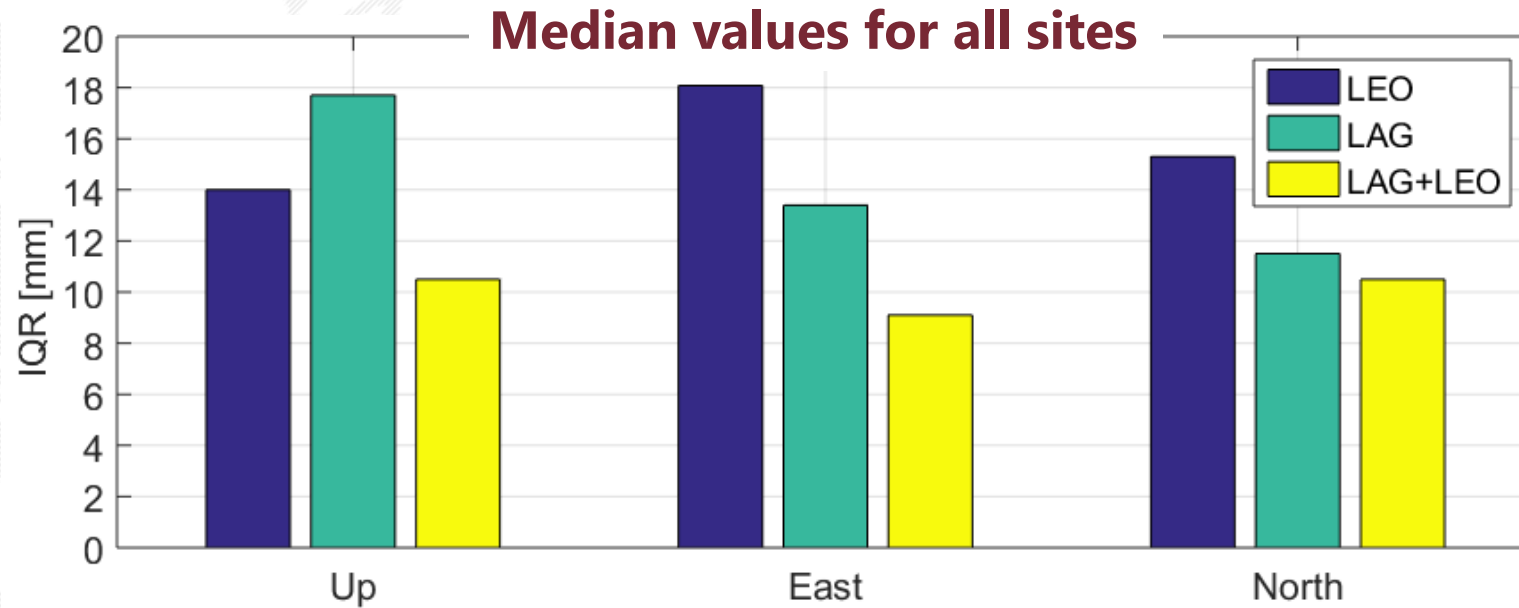
1-day, 3-day LEO solutions are insufficient for high-quality coordinates

Good global coverage can be achieved in **7-day solutions**

Station coordinates
(w.r.t ITRF2014)

Combined solution results and comparison

Station coordinates
(w.r.t ITRF2014)



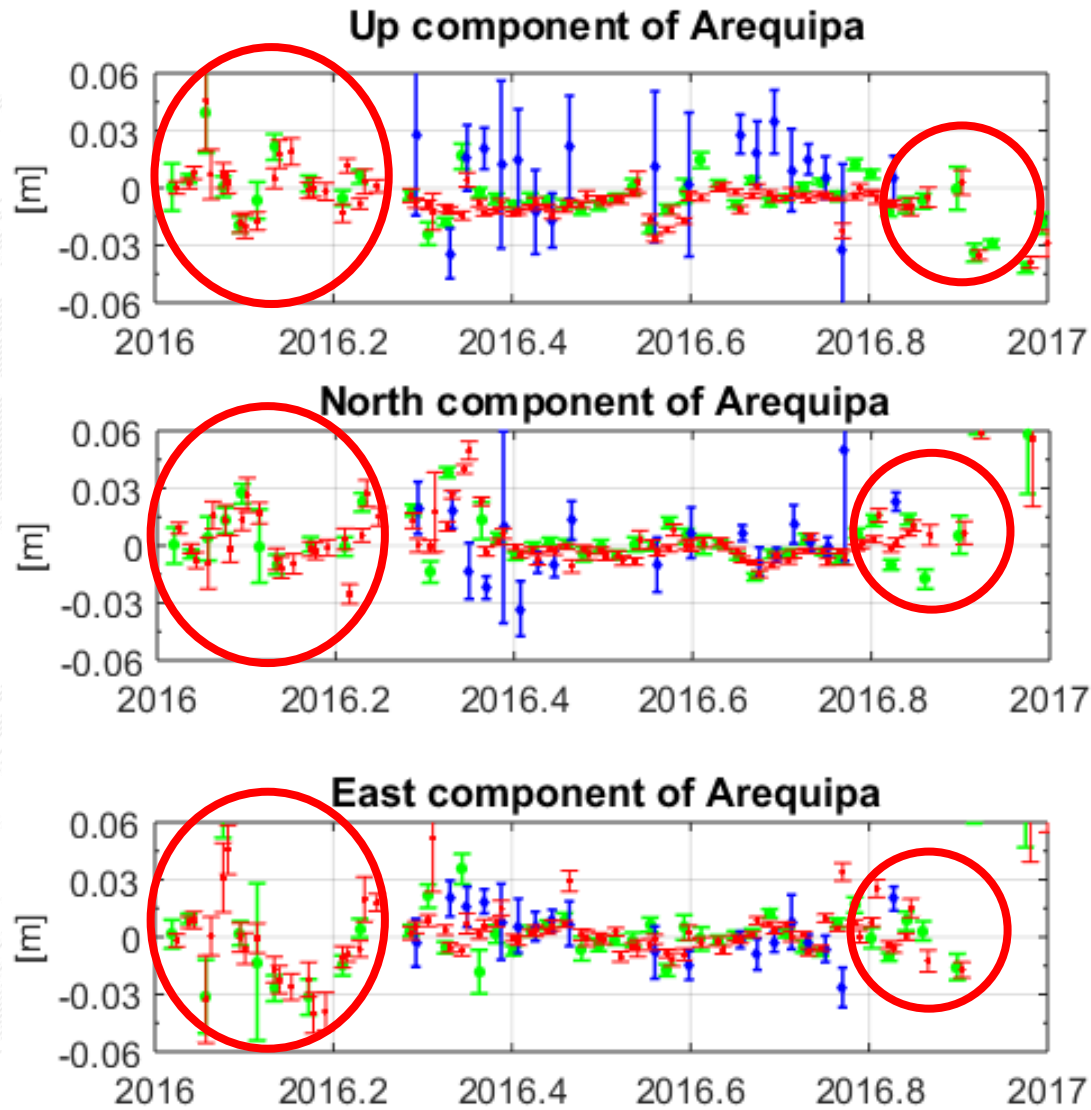
Determination strategy:

- NNT/NNR with estimation of parameters
- 7-day accumulated orbits
- Introduction of annual range bias for LEOs in all solutions
- Weighting of observations in LAG+LEO solution ($\sigma=10\text{mm}$ for LAG, $\sigma=20\text{mm}$ for LEOs)

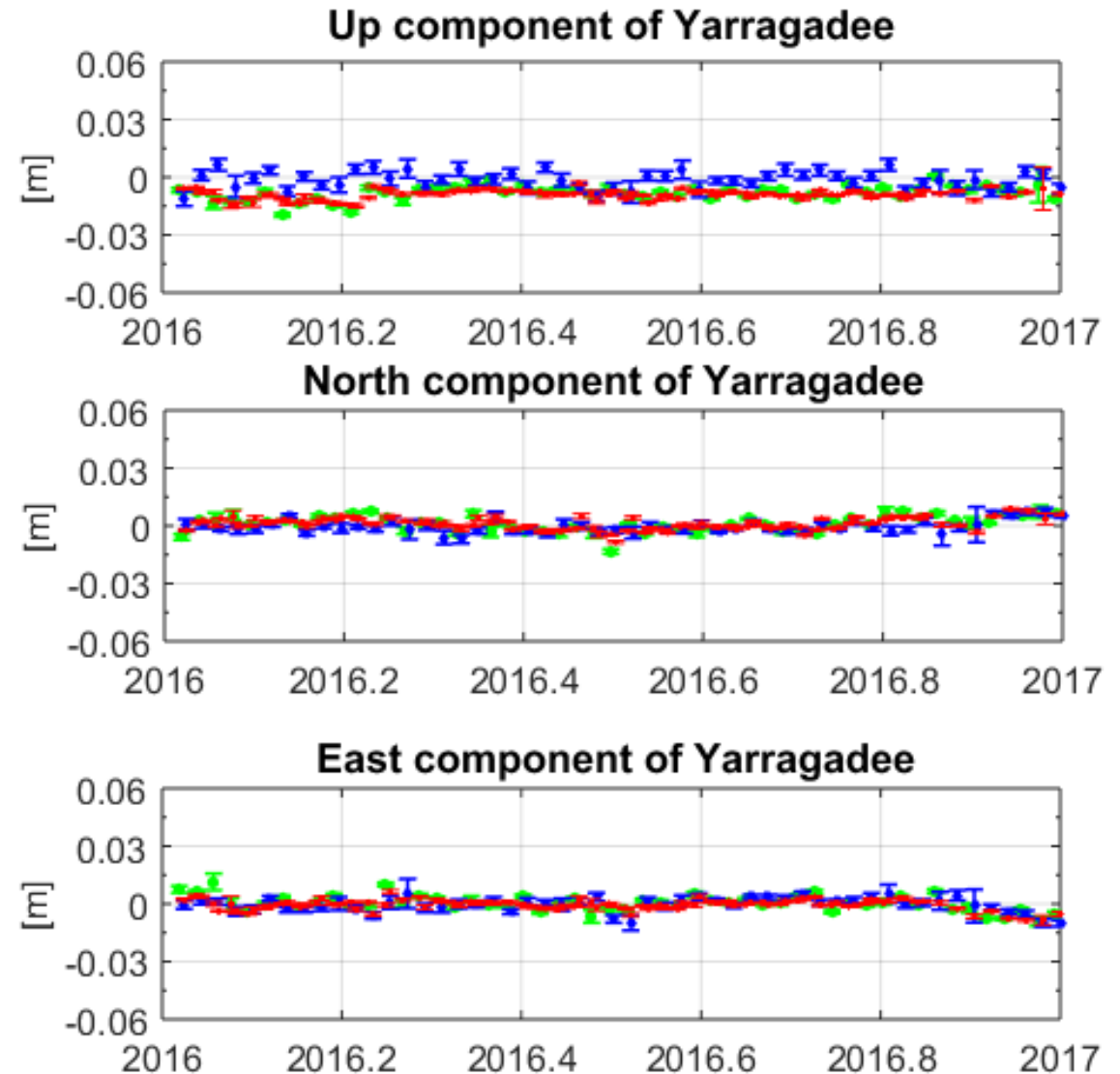
SLR sites statistics

- LEOs are slightly better for the Up component
- LAGEOS is better for the horizontal components
- **Best results** for all components in the **combined solution**

Number of obs. increase



LEOs-only solutions when LAGEOS not tracked-
number of obs. increase



Station coordinate repeatability for Yarragadee falls
between 5 and 11 (IQR) mm for individual components.

Summary

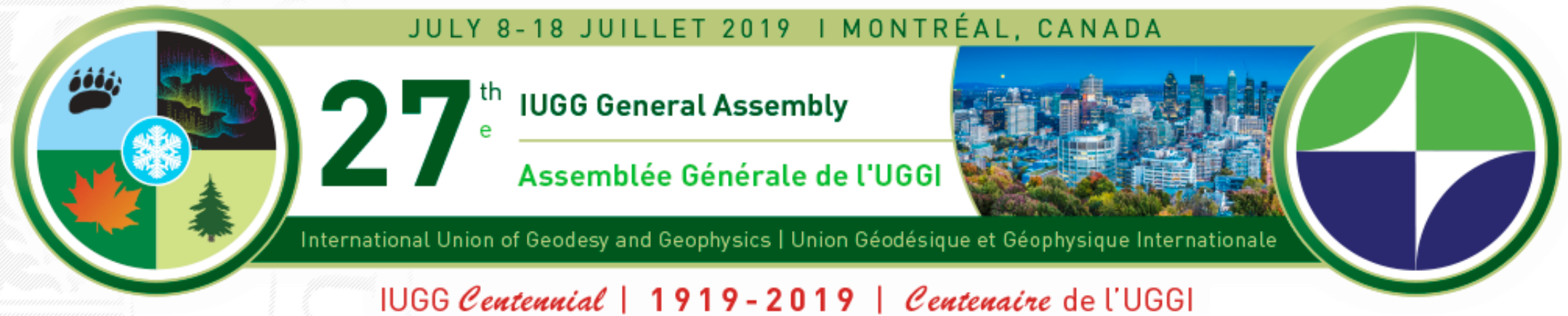
SLR stations have been providing **observations to a large number** of new active **LEOs and GNSS**

SLR observations to active LEO satellite require a **proper station bias calibration**

SLR data and high-quality GPS-based orbits of LEOs allow for the determination of **station coordinates with the accuracy of 10 mm** (core sites), even without network constraining

Reference frame realization based on SLR measurements to LEOs is possible

Best results are obtained from the combined LAGEOS+LEOs solution



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